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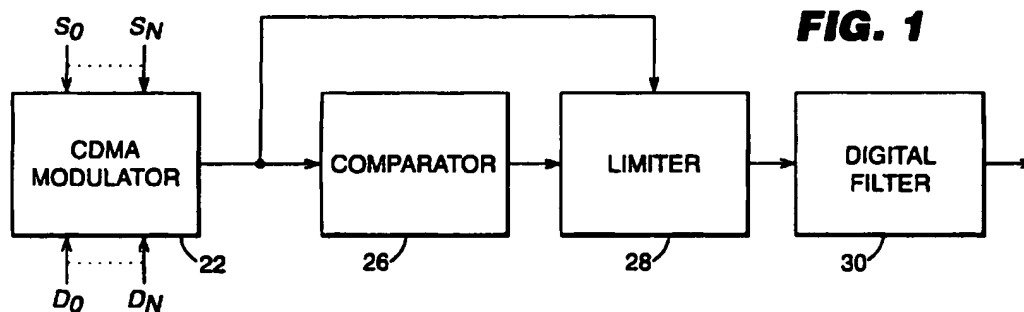
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(54) System and method to reduce the peak-to-average power ratio in a DS-CDMA transmitter

(57) A peak to average power ratio in a DS-CDMA transmitter is reduced by applying hard limiting to the signal while it is in digital form and prior to any frequency band filtering. In the case of a complex signal the clipping is done by making an approximation to the magnitude of the complex signal, comparing this to a threshold value and, whenever the magnitude exceeds the threshold, scaling the in-phase and quadrature com-

ponents by a factor equal to the ratio of the threshold value to the magnitude. The approximation to the magnitude may be made by reducing the signal to the first octant of the complex plane, evaluating a plurality of linear functions of the reduced in-phase and quadrature components and selecting the maximum value.



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## Description

### FIELD OF THE INVENTION

[0001] The present invention relates generally to a system and method for reducing the peak-to-average power ratio in multiple access communication systems, and more particularly to direct sequence code division multiple access (DS-CDMA) systems.

### BACKGROUND OF THE INVENTION

[0002] Direct sequence code division multiple access (DS-CDMA), a form of spread spectrum communication, provides multiple users access to a common communication channel, such as a radio band or optical fiber. A DS-CDMA transmitter combines a user data stream with a digital sequence, known as a spreading code, yielding a combination bit stream, sometimes referred to as a spread signal. A spreading code generator in the DS-CDMA transmitter generates the spreading code elements, or chips, at a rate that is typically faster than the user data stream. The spreading codes are designed to appear random, although the spreading codes are duplicated at a DS-CDMA receiver for use in recovery of a user data stream.

[0003] The spread signals are summed and filtered before transmission. The summing converts the multiple parallel combination bit streams to a serial signal, and filtering limits the frequency band occupied by the signal. Additional modulation techniques, such as Binary Phase Shift Keying (BPSK) or Quadrature Phase Shift Keying (QPSK), are used to modulate a carrier signal. If a transmitter uses BPSK, the summing operation provides a digital value representing the amplitude of the summed signal for each element of the spreading code. In QPSK, however, the summing operation yields a complex digital value having an in-phase and a quadrature component.

[0004] At the DS-CDMA receiver, a spreading code generator duplicates a user's spreading code for mixing with the received signal and recovery of the particular user data stream. Since each user has a unique spreading code, signals spread with other user codes, or signals not spread at all, resemble noise and are not recovered by the receiver. The use of different spreading code sequences by each user allows users to operate independently of each other, although all data streams are transmitted in the same band.

[0005] A problem with DS-CDMA signals is connected with peaks at the output of the summation. The CDMA modulation makes the data streams look like independent random signals, so the mean square sum is proportional to  $N$ , where  $N$  is the number of data streams. Thus, the average power is proportional to  $N$ . However, there is a finite probability that in a given chip period all of the CDMA modulated data streams will have their maximum value simultaneously. Thus the peak ampli-

tude will be proportional  $N$  and the peak power to  $N^2$ . The peak to average power (PAP) ratio thus increases with the number of data streams.

[0006] It is a concern in DS-CDMA systems, therefore, to experience signals with high peak to average power (PAP) ratios. A high PAP ratio reduces the efficiency of a transmitter power amplifier. If the power amplifier is allowed to saturate during periods of peak power, the distortion will cause harmonics of the input signal to appear outside the desired frequency band. The power level of the unwanted harmonics will vary with the performance of the individual power amplifier units. Out of band harmonics interfere with communication on adjacent channels.

[0007] Also, successful recovery of transmitted data in a DS-CDMA receiver relies upon the linearity of previous stages in the CDMA process. Maintaining linearity in a transmitter's power amplifier becomes progressively difficult as the number of users increases, due to the random nature of the signal generated by the summation of multiple spread signals. Due to the high PAP ratio, the power amplifier must generate sufficient mean power to maintain the signal level at the receiver but also remain linear during peak periods. Design and manufacture of such power amplifiers is costly and complex.

[0008] There is a certain tradeoff between distortion and power efficiency in a DS-CDMA transmitter. As the number of users increases, the PAP ratio also increases. The amount of tolerable distortion depends on spectral regulation and system requirements. Efficiency can be improved by allowing for more distortion, but with a corresponding degradation in the transmitted signal. Power amplifiers designed to accommodate high peaks decrease distortion, but such amplifiers are costly to design and manufacture. It is, therefore, a concern to reduce PAP ratio in a deterministic manner in order to achieve an optimal tradeoff.

[0009] For these reasons, it is highly desirable to reduce the PAP for simple and complex signals in a DS-CDMA transmitter without giving rise to excessive errors or spurious signal components.

### SUMMARY OF THE INVENTION

[0010] The present invention as set out in the claims provides a system and method to reduce peak to average power (PAP) ratio in spread spectrum transmitters. Hard limiting is applied to the output of the CDMA modulator while it is still in the form of a digital signal and prior to any frequency band filtering.

[0011] In one embodiment of the invention, a digital value is detected for each element of a spreading code. The detected digital value is compared to a given maximum threshold and to a given minimum threshold. If the detected digital value exceeds the maximum threshold, or is less than the minimum threshold, a limiting function is applied in the digital domain. The limiting function

sets the detected digital value to a predetermined maximum or to a predetermined minimum thereby clipping the signal. A step of band limiting by a stage of digital filtering substantially reduces out of band harmonics.

[0012] In another embodiment, digital values representing components of a complex signal are detected. The magnitude of the vector sum of the components of the complex signal is approximated and compared to a predetermined threshold magnitude. Where the approximated magnitude exceeds the threshold magnitude, each component of the vector sum is reduced by a scaling factor so that the magnitude of the complex signal approximately equals the threshold magnitude. Applying a stage of digital filtering substantially reduces out of band harmonics.

[0013] The present invention also teaches apparatus to reduce PAP ratio in multiple access transmitters. A detector receives at least one digital value for each element of a spreading code. A magnitude detector determines the approximate magnitude of the complex digital value. A comparator determines whether the detected magnitude exceeds a predetermined threshold. A limiter applied in the digital domain reduces the magnitude of the detected digital value to a predetermined value. Out of band harmonics are substantially reduced by a digital filter applied to the clipped signal.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0014] For a better understanding of the present invention, reference is made to the following description of exemplary embodiments thereof, considered in conjunction with the accompanying drawings, in which:

FIG. 1 is an exemplary embodiment of a system for reducing PAP ratio in a transmitter according to the present invention;

FIG. 2 is an alternative embodiment of a transmitter according to the present invention;

FIG. 3 shows an exemplary complex signal mapped to a coordinate plane;

FIG. 4 is a flow diagram of a magnitude approximation method in accordance with the principles of this invention;

FIG. 5 shows exemplary probability density functions.

#### DETAILED DESCRIPTION

[0015] Referring to Fig. 1, one exemplary embodiment of a DS-CDMA transmitter is shown according to the present invention.  $S_0$  to  $S_N$  represent spreading codes input to a CDMA modulator 22. Digital data streams  $D_0$  to  $D_N$  are also input to the CDMA modulator 22. The CDMA modulator 22 combines spreading codes  $S_0$  to  $S_N$  with data streams  $D_0$  to  $D_N$  and provides an output signal  $x[n]$  in the digital domain for every chip, or element, of the spreading codes. The output signal,  $x[n]$ , is

a summation of the combined spreading codes and data streams. In the present embodiment, the digital value,  $x[n]$ , is simple, or scalar, in nature.

[0016] A comparator 26 receives the digital value and compares the digital value to a given maximum (positive) threshold. If the digital value exceeds the maximum threshold, a limiter 28 provides a digital value equal to the maximum threshold thereby clipping the signal. The comparator 26 also compares the digital value to a given minimum (negative) threshold. If the digital value is less than the given minimum threshold, the limiter 28 clips the signal in the digital domain and provides a value equal to the minimum threshold. If the digital value lies between the threshold values it is passed on unchanged. A digital filter 30 band-limits the clipped signal prior to transmission to suppress out-of-band signal components.

[0017] In Fig. 2, a second embodiment of the invention is shown. In this embodiment of the invention, a DS-CDMA modulator 40 provides an in-phase component and a quadrature component in the digital domain for use in Quaternary Phase Shift Keying of the carrier at QPSK modulator. For simplicity, in-phase and quadrature are referred to as  $i$  and  $q$ , respectively. Referring to Fig. 3, an example of an output  $i$  and  $q$  for the DS-CDMA modulator 40 of Fig. 2 is shown mapped to the In-phase and Quadrature coordinate plane 58. The magnitude of the exemplary complex digital signal is the magnitude of the vector sum 60 of  $i$  and  $q$ .

[0018] A complex magnitude approximator 44 reflects  $i$  and  $q$  to the first octant of the complex plane. An approximation of the vector magnitude is then calculated by the magnitude approximator 44. A comparator 46 receives the magnitude approximation and compares the approximation to a predetermined threshold. If the approximation exceeds the threshold, then  $i$  and  $q$  are scaled at scaler 48 to provide a signal with a magnitude substantially equal to the threshold but with the same phase. If the approximate magnitude does not exceed the threshold value the scaler 48 passes the signal unchanged. Digital filter 50 band limits the complex signal in the digital domain to substantially reduce out of band harmonics.

[0019] A block diagram showing operation of one embodiment of a magnitude approximator 44 is shown in Fig. 4. An input of a plurality of bits is detected for  $i$  and  $q$ . As shown, an initial processing step 60 reflects  $i$  and  $q$  to the first octant of the  $i$  and  $q$  coordinate plane. Values for  $i$  and  $q$  after reflecting to the first octant, are referred to as  $i'$  and  $q'$  for simplicity. Thus  $i'$  is the greater and  $q'$  the lesser of  $|i|$  and  $|q|$ . The magnitude of the complex value is estimated by a step 62 of evaluating a plurality of linear functions and determining the maximum value. The maximum value is provided to the comparator 46 as the approximate magnitude of the complex digital value. The linear functions employed in step 62 in the present example are

$$z(n) = c(n, 0)i^n + c(n, 1)q^n$$

where  $n$  runs from 0 to 7 and the coefficients are given by

$c(0,0) = 0.99922162$	$c(0,1) = 0.04908861$
$c(1,0) = 0.98959857$	$c(1,1) = 0.14679308$
$c(2,0) = 0.97044514$	$c(2,1) = 0.24308385$
$c(3,0) = 0.94194580$	$c(3,1) = 0.33703360$
$c(4,0) = 0.90437500$	$c(4,1) = 0.42773752$
$c(5,0) = 0.85809458$	$c(5,1) = 0.51432210$
$c(6,0) = 0.80355024$	$c(6,1) = 0.59595348$
$c(7,0) = 0.74126727$	$c(7,1) = 0.67184549$

The number of coefficients can be increased or decreased dependent upon system requirements and desired accuracy for the magnitude approximation.

[0020] Referring again to Fig. 2, a comparator 46 compares the magnitude approximation to a predetermined threshold. If the magnitude approximation exceeds the predetermined threshold, a scaler 48 scales  $i$  and  $q$  by scaling factor equal to the threshold value divided by the magnitude approximation. Scaling  $i$  and  $q$  by such a factor yields a clipped magnitude approximately equal to the magnitude threshold. A digital filter 50 then band limits the clipped complex signal to suppress out of band frequency components.

[0021] One of the advantages of the use of hard limiting in the digital domain prior to any frequency band filtering is that PAP ratio reduction can be performed in a deterministic manner. For example, Fig. 5 shows a Probability Density Plot 120 for the output of an example 128-channel CDMA modulator superimposed on the Probability Density Function of a normal distribution 122 with the same standard deviation as the modulator. With a sufficient number of users, the output of the spreading process approximates to a normal distribution. As can be seen, the standard deviation for the modulator and the normal distribution is 17.4

[0022] The choice of clipping level is based upon the capability of the power amplifier. If a power amplifier supports a PAP ratio of 12db with tolerable distortion, the clipping threshold is set to plus or minus 4 standard deviations from zero. As shown in Fig. 5, four standard deviations 124 correspond to an amplitude of approximately 70, and clipping will therefore occur infrequently. If more frequent clipping is tolerable, a power amplifier supporting a smaller PAP ratio may be chosen.

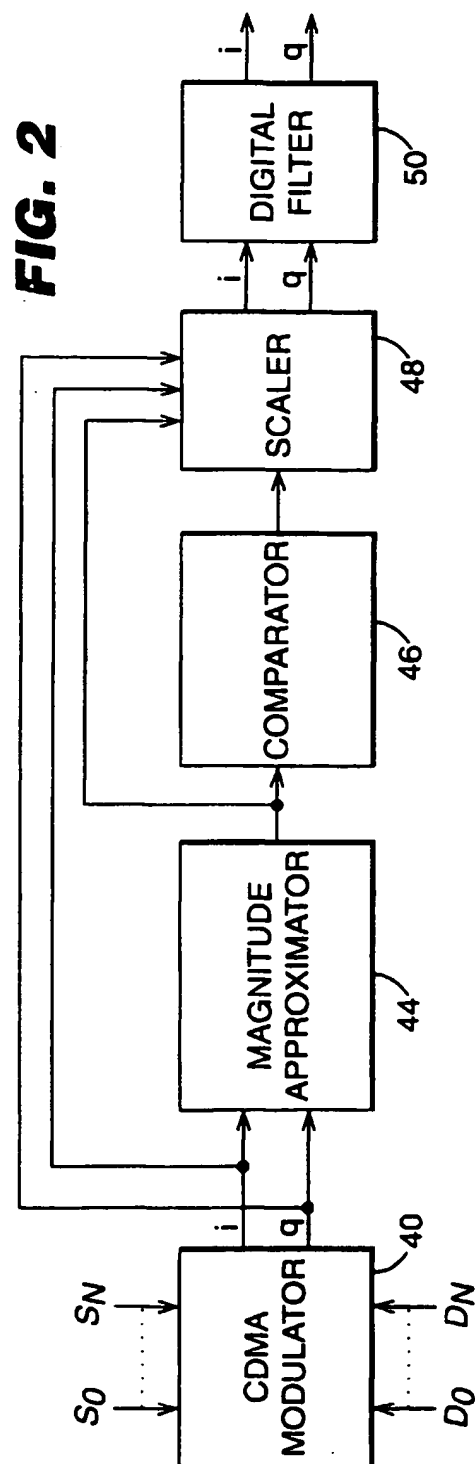
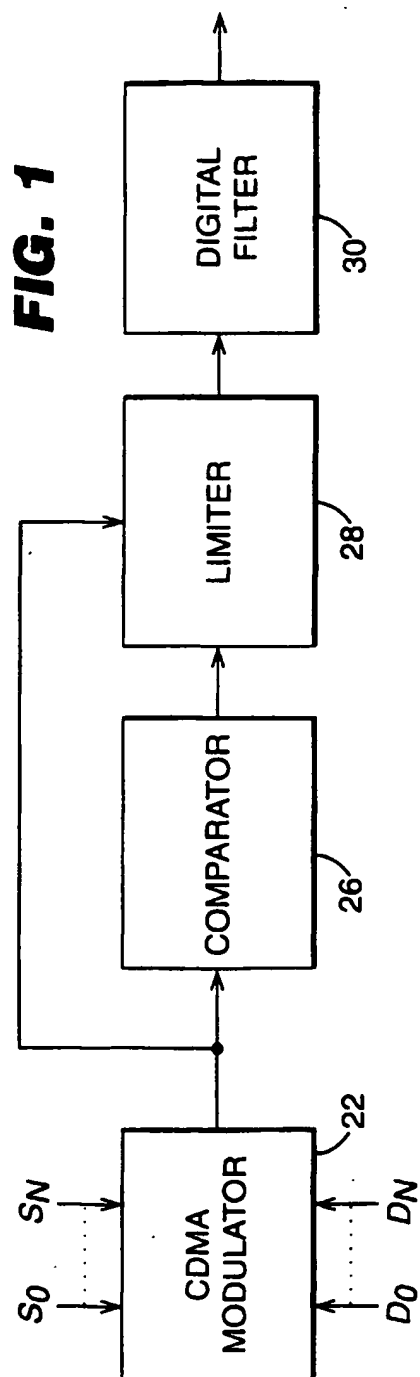
#### Claims

1. A method of reducing the peak to average power

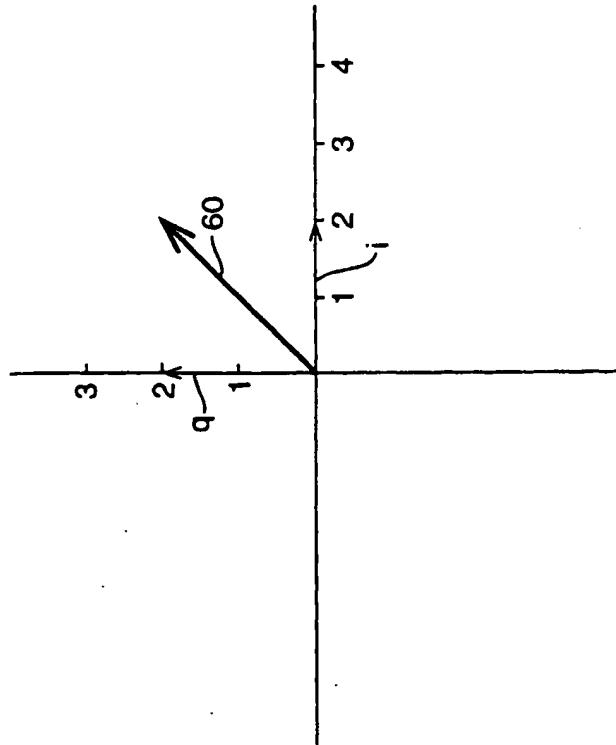
ratio of the signal produced by a code division multiple access modulator  
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- 5 applying hard limiting to the signal while it is in the form of a digital signal and has not been subject to any frequency band filtering.
- 10 A method as claimed in claim 1 wherein said signal is a single-component signal having a single value, and wherein said hard limiting comprises:
  - comparing said value with an upper threshold value;
  - 15 and, whenever said value exceeds said upper threshold value, substituting a signal having a value equal to said upper threshold value.
- 20 A method as claimed in claim 2 wherein said hard limiting further comprises:
  - comparing said value with a lower threshold value;
  - 25 and, whenever said value falls below said lower threshold value, substituting a signal having a value equal to said lower threshold value.
- 30 A method as claimed in claim 1 wherein said signal represents a complex signal and has an in-phase component and a quadrature component, and wherein said hard limiting comprises:
  - determining the magnitude of said complex signal;
  - 35 comparing said magnitude with a threshold value;
  - and, if said magnitude exceeds said threshold value, scaling said in-phase and quadrature components by a scaling factor equal to the ratio of said threshold value to said magnitude.
- 40 A method as claimed in claim 4 wherein said determining step comprises reducing said in-phase and quadrature components to a single octant of the complex plane, calculating a plurality of values, each value being a linear function of said reduced in-phase and quadrature components, and selecting the maximum of said values.
- 45 6. Transmitter apparatus including a CDMA modulator arranged to combine a plurality of input signals by code division multiple access modulation  
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  - 55 means for applying hard limiting to the combined signal while it is in the form of a digital signal and has not been subject to any frequency band filtering.

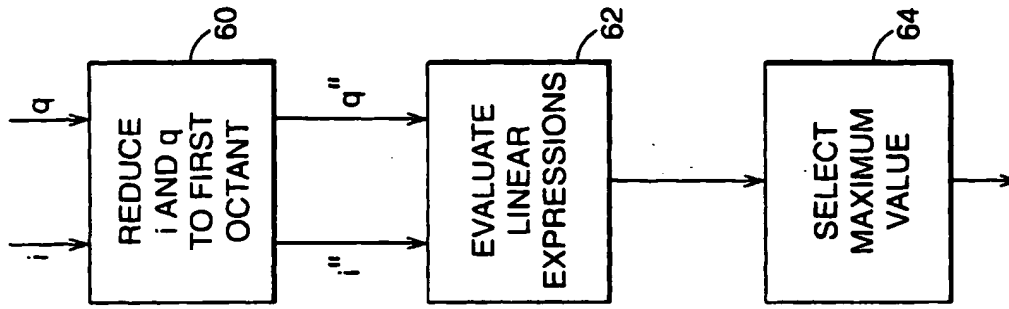
7. Apparatus as claimed in claim 6 wherein said signal is a single-component signal having a single value, and wherein said means for applying hard limiting comprises means for comparing said value with an upper threshold value and, whenever said value exceeds said upper threshold value substituting a signal having a value equal to said upper threshold value. 5
8. Apparatus as claimed in claim 7 wherein said comparing means is also arranged to compare said value with a lower threshold value and, whenever said value falls below said lower threshold value, substituting a signal having a value equal to said lower threshold value. 10 15
9. Apparatus as claimed in claim 6 wherein said signal represents a complex signal and has an in-phase component and a quadrature component, and wherein said means for applying hard limiting comprises: 20
- means for determining the magnitudes of said complex signal;  
and means for comparing said magnitude with a threshold value and, if said magnitude exceeds said threshold value, scaling said in-phase and quadrature components by a scaling factor equal to the ratio of said threshold value to said magnitude. 25 30
10. Apparatus as claimed in claim 9 wherein said determining means comprises means arranged to reduce said in-phase and quadrature components to a single octant of the complex plane, calculate a plurality of values each value being a linear function of said reduced in phase and quadrature components, and select the maximum of said values. 35 40 45 50 55

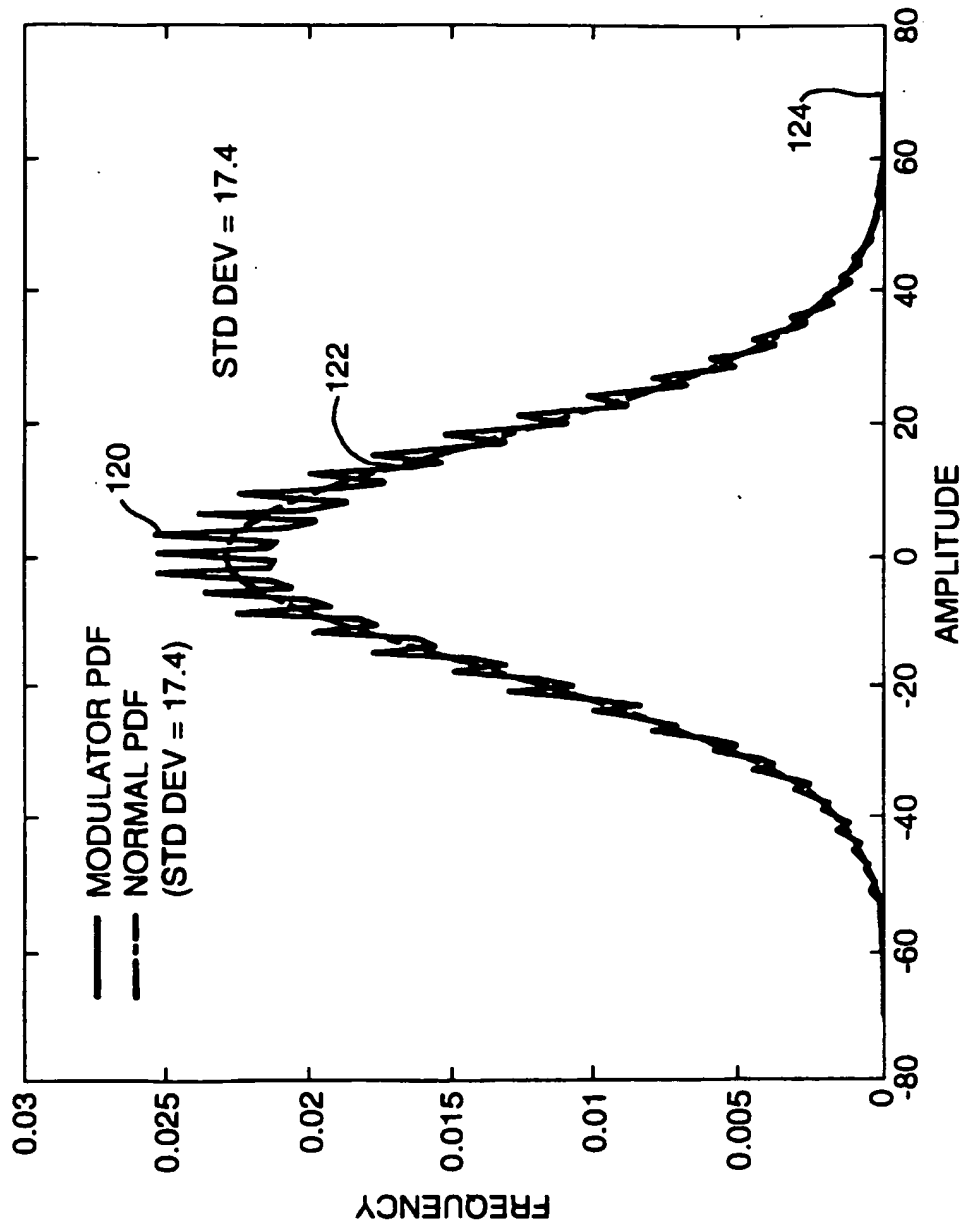


**FIG. 3**



**FIG. 4**



**FIG. 5**





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## EUROPEAN SEARCH REPORT

Application Number  
EP 98 30 1648

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X A	EP 0 751 630 A (NIPPON ELECTRIC CO) 2 January 1997 * column 4, line 4 - column 5, line 33; figures 2,3,8,10 * * column 10, line 40 - column 11, line 27 * ---	1,2,4-7, 9,10 3,8	H04B1/707
A	US 5 668 806 A (ARAI YASUYUKI ET AL) 16 September 1997 * column 3, line 1 - line 42; figures 1A,4A * ---	1-10	
E A	US 5 742 595 A (BHAGALIA SHASHIKANT) 21 April 1998 * column 1, line 22 - column 2, line 26; figure 19 * -----	1-4,6-9 5,10	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			H04B
The present search report has been drawn up for all claims			
Place of search <b>THE HAGUE</b>		Date of completion of the search <b>7 August 1998</b>	Examiner <b>Andersen, J.G.</b>
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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